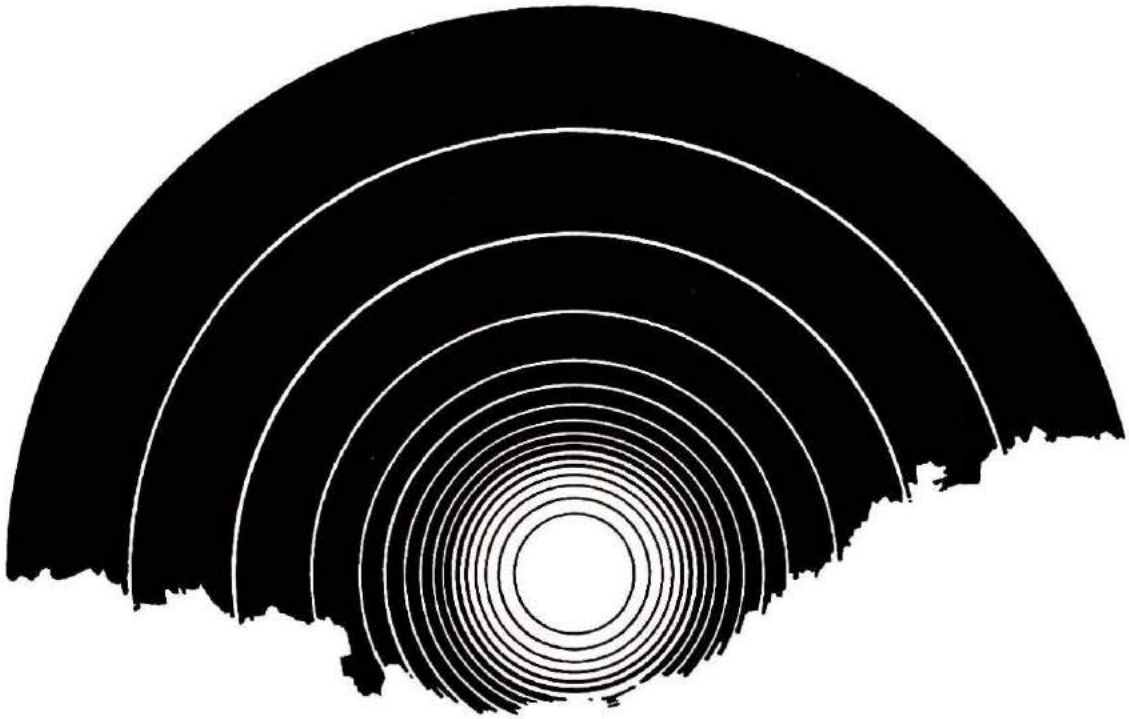

A GUIDE TO VHF PROPAGATION

Part 1

BY JAY BUSCEMI, K2OVS

The amateur bands of 50 through 450 MHz offer some of the most exciting propagation effects in the radio spectrum. Most casual vhf operators are unaware of these effects and fail to take full advantage of them. In this article I will categorize the major modes of propagation in the vhf spectrum and provide some guidance to the uninitiated in how to best make use of these higher bands.

Most extended-range vhf communications take advantage of natural meteorological phenomena which affect radio propagation in the earth's atmosphere up as high as about 400 km (250 miles). **Fig. 1** depicts the various "layers" which you can use to extend vhf communication range. The actual height of these layers and their ability to reflect or refract vhf signals varies with the time of day, time of year, sunspot activity level, and local weather conditions. They are presented here only to familiarize you with their existence; more detailed descriptions of their behavior are available in *The Radio Amateur's Handbook* and other literature.[1,2]

A brief word about equipment and operating techniques is appropriate at this point. In general, most DX communication is carried out on CW or ssb in the lower portions of the vhf band segments. These modes can be successfully used by a station with 70 to 100 watts output, a medium-size beam antenna (10-16 elements, horizontally polarized), and a receiver with a 2-3 dB noise figure. The popular multi-mode transceivers used in conjunc-

tion with a small amplifier will work quite successfully, particularly on 2 meters. Certain DX modes, such as E-skip and TE scatter, have been used by 10-20 watt stations — so more elaborate equipment is not always a necessity. The most popular calling and listening frequencies used in the continental U.S. are these:

6 meters:	50.100 CW, 50.110 usb
2 meters:	144.100 CW, 144.210 usb, and 146.52 fm (vertical polarization)
1¼ meters:	220.010 CW, 220.050 usb
70 cm:	432.090 CW, 432.100 usb

When conditions are good for band openings, you will almost always make the earliest contacts by monitoring these frequencies. As the conditions improve, stations tend to spread out above and below these frequencies by 20 kHz or so. Tuning around will pay off as the band gets crowded.

The major modes of terrestrial vhf propagation are shown in **Fig. 2**. The frequency of occurrence of these modes is based on my observations over a 20-year period from the New York City/Long Island area. Obviously, those modes affected primarily by local geography (such as tropo ducting and temperature inversions) will vary greatly, depending upon location.

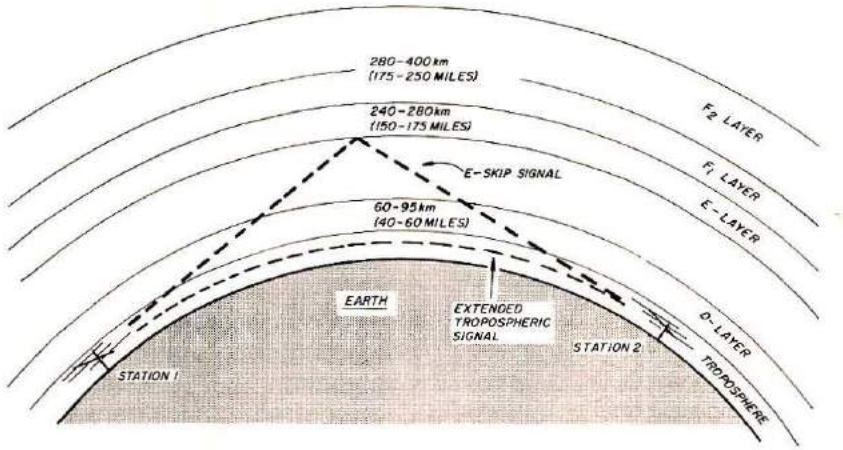

Fig. 1. The space through which radio signals propagate is made up of several layers. The lower one, called troposphere, bends the signal path by temperature differences or disturbances in the air mass. Higher layers, in the ionosphere, are subject to varying degrees of ionization — which either helps or hinders the signals as they pass through. The layers are not in fixed positions, but rather shift up and down depending upon weather conditions, solar activity, and the time of day.

Specific propagation modes

Normal coverage: vhf propagation is generally believed to be line-of-sight, that is, the radio path is the same as an optical path. In practice, the so-called normal vhf range is actually 7-15 per cent farther than the optical path, a result of the presence of moisture in the atmosphere and the bending of radio waves back toward the earth.[3] Over flat terrain, a rough calculation of a station's line-of-sight distance can be made by the following equation:

$$D \text{ (kilometers)} = 4.1\sqrt{\text{height of antenna in meters}}$$

$$D \text{ (in miles)} = 1.4\sqrt{\text{height of antenna in feet}}$$

Fig. 2. The type of propagation of vhf signals varies from month to month, and some modes appear only at certain seasons. This chart shows what you can expect in the way of normal or exotic conditions on the different bands.

Mode	Approximate useful days per year 50 MHz	144 MHz	220 MHz	432 MHz	Notes
Normal coverage	300-320	300-350	300-350	300-350	Slightly beyond line-of-sight, affected by local terrain.
Temperature inversion	20- 60	20- 60	25- 60	25- 60	Affected by local weather patterns, best in spring and fall.
E-layer skip	50- 70	2- 10	*	*	Best in June, July, and January.
Tropospheric ducting	0- 10	5- 20	10- 20	10- 30	Due to large stationary weather systems.
Back/forward scatter	70-120	10- 20	*	*	Combination of E, F layer and meteors.
Aurora	10- 40	10- 30	10- 15	0- 5	Generally higher latitude effect.
Intense meteor scatter	20- 40	10- 30	5- 20	0- 5	Best during major showers in August and December.
Trans-equatorial scatter	10- 50	5- 20	*	*	Generally middle latitude effect.
F-layer skip	0- 10	*	*	*	Usually during sunspot peak years.

* Insufficient data

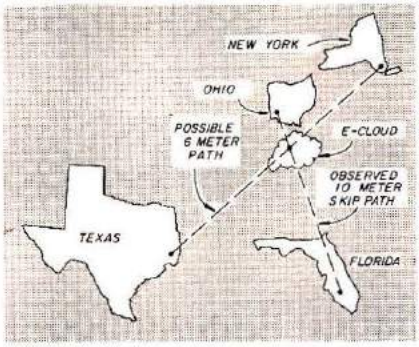

Fig. 3. Sometimes an observed skip opening on a lower band can tip you off to good conditions for 6 or 2 meters. E-layer clouds move fast, so a path may not exist for very long.

For example, if a vhf antenna is 15 meters (50 feet) high, the approximate line-of-sight distance for the horizon is

$$D = 4.1\sqrt{15.24} = 16 \text{ km}$$

$$D = 1.4\sqrt{50} = 10 \text{ miles}$$

If the station on the other end of the path has an antenna that is at the same elevation, the maximum two-way line-of-sight distance is twice this value, or approximately 32 km (20 miles). The antenna height should include the ground elevation if it is significantly different from the surrounding terrain.

Some 10-15 per cent of the time, local conditions will tend to be subnormal due to very low humidity (no refraction) or heavy rain or snow (high absorption). During times of the year when foliage thickens and absorbs moisture, higher-than-normal signal attenuation should be expected.[4] The traditional adage "get your antenna as high as possible" helps overcome this effect.

Obviously, many other factors affect a station's coverage. A large hill or mountain will block vhf signals, particularly one close to the station. Tipping the antenna up from the horizontal, when it is aimed at a large obstruction, can sometimes be used to scatter vhf signals. Man-made structures such as buildings or bridges can be used to some advantage in extending local coverage. Several stations on Long Island, New York, have used the Throg's Neck Bridge in New York City to reflect two-meter signals into northern New Jersey, as an example.

Temperature inversion

By far the most common form of extended-range propagation is observed on the vhf bands during a temperature inversion, that is, when bending (refracting) of the wave in the troposphere is caused by a reversal of the normal height-to-temperature relationship. Normally, the temperature decreases rapidly with height above the ground up to 15 km (50000 feet) or so. When this condition gets reversed at some point in the troposphere, vhf signals tend to be bent back toward the earth over extended distances — out to twice or three times the normal range.[3] Inversions are particularly common along coastal areas in the spring and fall months due to the increased temperature difference between the land and the water. Intermixing of warm and cool air at altitudes of up to 16 km (10 miles) creates the inversion. Propagation is generally enhanced along these mixing lines, which tend to follow the coastline. As an example, stations on the coast of Maine regularly can work as far south as Virginia at least 60 to 70 days a year with good signal levels. Storm centers, well-defined weather fronts, and other atmospheric disturbances also produce local temperature inversions along their front lines.

Propagation by this mode is primarily a nighttime effect; the sun's heat during the day tends to smooth the temperature *versus* curve height. After dark, the air-mass mixing begins and improves conditions throughout the night. Conditions often reach a peak in early morning, perhaps 7:00-9:00 local time.

One of the best indicators of a temperature inversion is the increase in signal strength on fm repeaters. Check the common frequencies in your area to learn the direction and intensity of the improved signal conditions. Weak vhf and uhf TV signals on locally unoccupied channels also provide an indication of good conditions. A temperature inversion can be quite selective in terms of station locations. Amateurs not very far apart may experience vastly different signal strengths from a distant station as the temperature-inverted air layers drift around. Listen to what is being worked by nearby stations to determine the best direction as the evening progresses.

Temperature inversions tend to favor the higher-frequency bands for a given set of conditions. Many Amateurs will move up to 220 or 432 MHz when conditions are good on six or two meters, often finding stronger signals over the same path. However, the maximum length of the path than can be worked is generally the same for similarly equipped stations. Inversions that affect vhf signals seem to have well-defined geographical start and stop points, regardless of the band used.

E-Layer skip

The ionospheric E-layer, responsible for short skip on the high-frequency bands, can become sufficiently ionized in patches to reflect six and two meter signals with very high received-signal levels. E-skip is

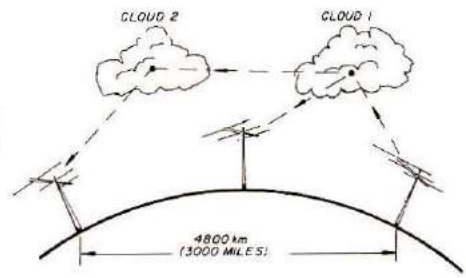

Fig. 4. A rare occurrence that pays off in very good DX on 6 or 2 meters is the positioning of two E clouds so that you can extend your range far beyond normal.

generally observable in January, June, and July, but it can occur at any time of the year. These patches of high ionization, called "sporadic-E clouds," are generated around the equator and travel in a northwesterly direction across the country. The clouds are generated in bunches, and have an apparent size of up to several hundred feet across.

Several good indicators are available to help you identify the presence of sporadic-E clouds. The 10-meter band is one of the best; when strong stations are being heard at distances below 500-600 km (300-400 miles), the maximum usable frequency (MUF) of the E-clouds is going up. A check of the six-meter band should find strong stations out to 1600 km (1000 miles) or so. As the skip shortens on six-meters, the two-meter band may begin to open and E-skip will be observed there. The vhf TV channels provide a constant monitor on E-skip conditions. When channels 2 or 3 in your area show signs of co-channel (same-frequency) interference, six meters is open in the same direction as the interfering TV station. As co-channel interference is observed on TV channels 4, 5, 6, and the fm broadcast band, it is likely that E-skip will start on two meters.

Because the clouds are physically small, some knowledge of their location at any given time is important so you can aim your antenna at the cloud. To approximate the cloud's location, listen on a lower frequency (10 meters) and note the location of stations talking to each other. For example, if Florida stations are working Ohio, the cloud is located somewhere near the midpoint of that path, maybe over Tennessee. Aiming your antenna towards Tennessee on the next higher band may allow you to work Texas, if you are located in the New York-New Jersey area. Constant observation of the next lower frequency band will allow you to readjust your antenna heading as the E-cloud moves (**Fig. 3**).

Signal levels tend to be very strong when reflected by the E-clouds. Many stations running 10 watts or so have worked over 1200-1600 km (800-1000 mile) paths with S9 signals. Another characteristic of the E-skip signals is their "there-or-not" nature. Signals can disappear in mid-sentence and reappear just as quickly. Short CQs and listening periods (15 seconds or so) are necessary to take full advantage of the shorter openings, especially on two meters. E-skip on six meters can last hours; two meter openings rarely exceed 15 minutes or so. The best listening times are mid morning and early evening, up to 9:00 p.m. local time, although E-skip has been observed around the clock on occasion.

Double-hop E-skip has been observed on six meters, extending the skip range out to 4800 km (3000 miles) or more. This requires two or more E-clouds to be in just the right position (**Fig. 4**).

Tropospheric ducting

Large, stable, high-pressure systems can form elevated ducts with fairly well-defined boundaries at altitudes of up to a few miles. These ducts act as waveguides for vhf signals and can propagate the signals over distances of 6500 km (4000 miles) with almost no loss of strength. Ducts of this type have been responsible for Hawaii-to-California and New York-to-Bermuda contacts on two meters in recent years.[5,6]

Weather maps provide the best source of information for predicting the possibility of ducting. A large, stable, slow-moving, high-pressure center moving across the country may produce ducts along its front lines. Ducts tend to have well-defined boundaries, so stations a few miles apart may experience vastly different signal levels. A duct must terminate

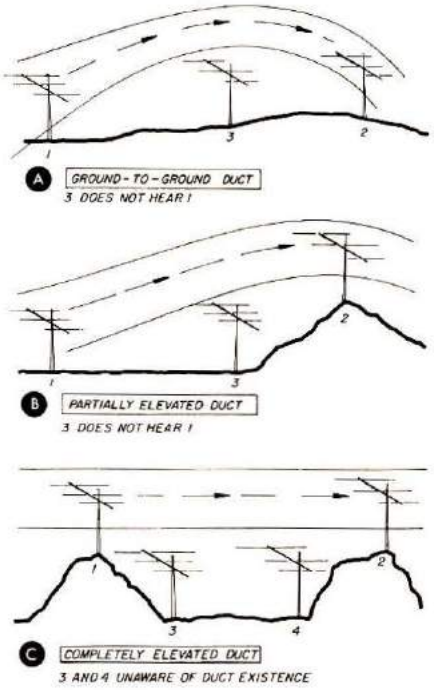

Fig. 5. Tropospheric ducting can propagate signals with very little loss, but you have to be in the right place to use this mode. Some ducts form so high that only aircraft or mountain tops are in the right spot, but enough do end at ground level to keep vhf work interesting.

at some ground location to be useful; totally elevated ducts are useful only for aircraft or stations at high elevations. Some of the Hawaii-to-California openings were available only to stations on mountain tops; the duct never dropped below approximately 1500 km (5,000 feet), (see **Fig. 5**).

Once a duct is formed, it may last several hours or days, drifting both in starting point and height. Furthermore, certain frequency bands may be favored at different times. It is not unusual for signals to be much stronger on 432 than on 144 MHz, so changing bands can be a good idea. Keep a watch on unused TV channels, particularly 7 to 13 and 14 to 50 for indications of duct formations. Keep in mind that most TV transmitter sites are located at relatively high elevations, so a distant station's signal may be entering a partially elevated duct at one end of the path at an elevation unaccessible to amateur stations. This same

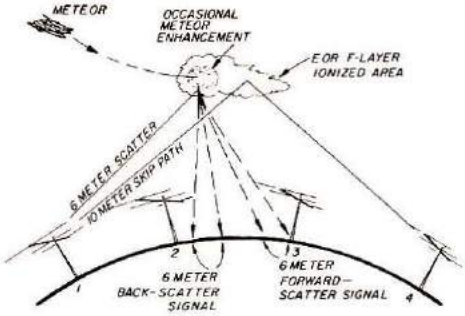

Fig. 6. Scatter signals occur when there is not enough ionization to cause loud-signal propagation, but there is some improvement over normal conditions. Random meteors sometimes add to the effect.

effect can occur with repeater signals, as repeaters are generally at higher elevations. However, these indicators will tip you off to the existence of a duct which may descend and become usable.

Apparently, ducting occurs much more often than was once suspected. Commercial and military air-communications links and radar are frequently distrupted or confused by tropo ducting.

Ducts are sometimes optically visible, particularly in areas with high dust or smog levels. The dust particles in the air seem to concentrate near the duct boundary, producing a dark band across the sky. An observer can estimate the elevation of the duct and possibly its end point. In southern California, some operators take mobile or portable vhf stations to the higher areas when an elevated duct is observed near the coast line. This technique has resulted in many low-power, long-distance contacts on two meters.

Back and forward scatter

Since ionized patches and layers in the ionosphere are far from uniform in shape or surface consistency, signals striking them do not always reflect back down to earth in a straight line, as optical theory would predict. Some portion of the energy scatters off the ionized area in arbitrary directions (**Fig. 6**). Signals bent back toward the transmitter are commonly called "back-scatter" signals; those reflected ahead or to the side of the reflecting layer are called "forward-scatter" signals.

Ionospheric scatter signals are generally usable above the normal maximum usable frequency (MUF) of the reflecting layer. For example, an ionized area of the F_2 layer may be producing strong skip signals on ten meters from New York to California but may not be sufficiently ionized to propagate six meter signals. By aiming an antenna toward the reflecting area, your weak six meter scatter signals may be available to a station at the end of the 10-meter circuit. Ionospheric scatter signals may be momentarily enhanced by meteors entering the atmosphere, temporarily raising the effective MUF of the ionized area in use.

Operating via the scatter mode is not limited to the D, E, and F layer ionized areas; any physical irregularity in the earth's troposphere can produce usable scatter signals. A storm center, weather front, or other disturbance along the radio path can be used to produce contacts over extended distances (**Fig. 7**). Thunderstorm scattering, although potentially dangerous (most stations prefer to ground their antennas during a thunderstorm), has been successfully used for extended-range two-meter contacts in the Midwest, as lightning produces highly ionized columns in the troposphere.

Scatter signals tend to be much weaker than most VHF propagation modes, so high power, large antenna arrays, and low-noise-figure receivers will improve your ability to successfully use this mode. Except for momentary meteor enhancement, fading tends to be slow and the scatter path may be open for extended periods of time with relatively consistent, but weak, signals. Because of the weak-signal nature of this mode, TV and fm broadcast channels are not generally affected enough to be

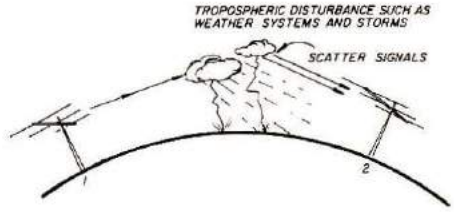

Fig. 7. Almost any discontinuity in the atmosphere can cause scatter-signal propagation. Storms and storm systems should be watched closely. The highly ionized path of a lightning bolt can provide a momentary increase in signal strength — sometimes many dB above normal.

usable indicators. However, strong short-skip on 10 meters may indicate potential ionospheric scatter signals on six meters, and local disturbed-weather patterns may produce tropospheric scatter on two meters and up.

There's a lot more to vhf propagation than I've covered so far, but I'll have to finish it up next month. The modes just explained have been, for the most part, supported by phenomena in the lower and middle atmosphere. Next month I'll get to the higher limits of the ionosphere, and tell you about some types of propagation which are understood but infrequent in occurence, and about a relatively new mode that offers Amateurs a chance to explore, learn, and add to the body of scientific knowledge.

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HRH

A GUIDE TO VHF PROPAGATION

Part 2

BY JAY BUSCEMI, K2OVS

Last month I talked about several of the loud-signal modes of propagation — modes that allowed a signal of only a few watts to bounce down to you from thousands of miles away, yet be as loud as if they were coming across town. There are other conditions which help you chase vhf DX, with quite variable signal strength and quality. In fact, one of these modes really garbles the signal, causing it to get a "buzz" on it, as the vernacular has it. As with many other modes, it requires cooperation from the sun in the form of emissions that cause the "northern lights," or Aurora Borealis.

Aurora

The aurora borealis, commonly known as the northern lights, will reflect vhf signals when its ionization level gets sufficiently high. Solar disturbances emit bursts of high-energy particles which arrive at the earth a few days after their occurrence. The best indicator of an impending aurora is the appearance of weak, fluttery signals on the high-frequency bands, particularly 80 and 40 meters. A buzz or raspiness appears on CW signals, and voice signals exhibit severe distortion, making some of them unreadable. Amateurs in the higher latitudes can visually observe the auroral display in the northern sky.

All bands from 50 through 432 MHz are affected by auroral propagation to some extent, although 6 and 2 meters have the most pronounced effects. As a general rule, auroral activity tends to peak between 4:00 and 8:00 p.m. local time, although at times sufficient ionization in the auroral curtain will persist for several hours.

The characteristic "buzz" of auroral signals is caused by the randomly ionized nature of the aurora. A signal directed at the aurora produces a large number of reflected signals, see **Fig. 8**, all slightly different in phase. The received signal is actually a combination of all these

phase-shifted, reflected, signals. This has the effect of producing a wide, phase-modulated carrier in your receiver. A voice signal is extremely distorted at the receiving station, usually to the point where it is very difficult to understand. Therefore, most auroral work is down on CW, especially at frequencies above 144 MHz.

Auroral ionization is produced near the north pole, so both the transmitting and receiving stations should point their antennas in a generally northern direction. Final aiming of the array can be accomplished by peaking it for maximum "buzz" on a local station. The optimum direction may vary by as much as 30 degrees over a period of two to three hours, so some repeaking is generally required.

Aurora tends to favor the northern latitudes; it is virtually unknown in Florida or southern California, but quite common in Maine and Wisconsin. Working distances between stations average out to about 900 km (600 miles), although occasional contacts to 1600 km (1000 miles) or so have been reported. High-power transmitters and directional antennas on both ends of the communications path extend the workable range considerably, especially under marginal conditions near the beginning and end of the auroral disturbance.

Meteor scatter

When meteors pass through the upper levels of the earth's atmosphere they produce intense patches of ionization which can reflect vhf signals.[7] Random meteors are always producing this ionization to some extent, but periodic streams of meteors, called "showers" greatly increase the average ionization level. The Perseids in August and the Geminids in December are the most consistent showers of reasonable intensity, so they are the most commonly used by Amateurs.

Of all the vhf DX modes, meteor-scatter requires the most attention to time and frequency synchronization. On two meters, almost all meteor-scatter work is done on prearranged schedules; random contacts are difficult at best. High-speed CW is preferred, although many voice contacts are made each year. Minimum output power should be around 100 watts, and you should have a 10-dB gain antenna. A good noise figure in the receiver also helps considerably.

The optimum distance between scheduling stations is between 800 and 1600 km (500 and 1000 miles). Closer-in work has been attempted by stations using an elevation control on antenna arrays to tilt the antenna up 10-20 degrees from the horizon. Ideally, antennas should be aimed at the ionized area, but for practical antenna beamwidths (greater than 10 degrees), both stations should aim their antennas in the general direction of each other. Schedules are generally carried out on unpopular frequencies to avoid QRM by local stations; 50.0 to 50.5 and 144.2 to 144.5 MHz are commonly used for schedules on six and two meters, respectively.

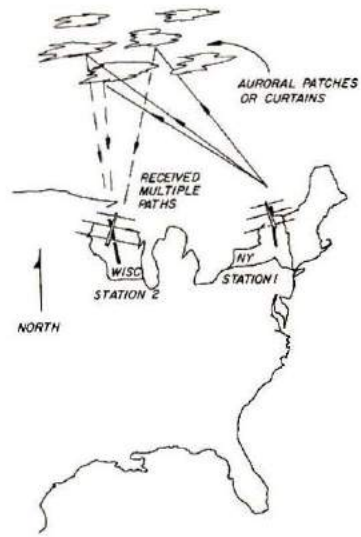

Fig. 8. The Aurora Borealis will reflect signals from the highly ionized patches or curtains. Because the curtains and streamers flicker and shift about, the signals may not be steady, and the varying density of the ionized patches creates multiple reflections that give the signal a distorted, sometimes watery, sound. CW usually sounds raspy, but can be copied with ease — voice is often distorted beyond recognition. Auroral openings are more prevalent in the northern latitudes, but have been known to get as far south as Georgia and Arkansas.

The minimum exchanges of information and the manner in which it is given is well established for meteor-scatter contacts.[8] Both calls and signal reports must be exchanged and confirmed by each station for a contact to be considered valid. This is generally mandatory because of the prearranged schedules (both stations know each other's call before the contact is made). It is customary for the westernmost station to transmit the first and third 15-second period of each minute; the easternmost station transmits the second and fourth 15-second periods. Schedules are maintained for at least one-half hour, and one- to two-hour schedules are common.

In your first attempt at meteor-scatter, you should arrange a schedule with an Amateur familiar with the mode. For the August Perseids and the December Geminids, it is best to arrange schedules with these stations at least a month in advance; they usually are saturated with schedule requests as the major showers get near. When setting up a schedule, specify the exact frequency, mode (CW or ssb), starting time, length of the schedule, and the number of days the attempt will be made. Also make sure you exchange telephone numbers so last-minute cancellations can be made. There is nothing so frustrating as keeping a two-hour schedule and finding out that the other station was called out of town at the last minute and couldn't reach you to cancel the attempt.

Many stations now use automatic CW memory keyers such as the AUTEK Research MK-1. These programmable keyers allow the operator essentially to preprogram most of the contact and avoid the tired arms and sending errors. In addition,

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Trans-equatorial scatter

Very little is known about the physical nature, and relationship to the solar cycle, of trans-equatorial (TE) scatter. Contacts as far as 4800 km (3000 miles) have been made on two meters using this mode in recent years. Apparently a belt of ionized particles sometimes exists near the equator, and stations on either side of the equator can use this band of particles to reflect six- and two-meter signals in a generally north-south path.

Most successful TE work to date has been accomplished on six meters, but signals on 144 and 432 MHz have been heard.[9] The TE effect seems to be available only to stations in the middle latitudes and only in the north-south direction. When conditions are optimum, as little as 10 watts output has produced successful contacts. 145.1 MHz on two meters is presently being used as the most common calling frequency. Amateurs in the southern U.S. should look south in the evenings for potential TE contacts with South America, particularly Venezuela and Argentina. Signals tend to be weak and fluttery, and ssb is preferred. Recent work has indicated that there may be some significant relationship between major solar disturbances and TE enhancement; the same solar flare that influences aurora activity may also enhance TE signal levels.

TE scatter offers a real challenge to the vhf operator because it is a relatively uncharted area of propagation. Successful contacts via this mode should be reported and published so the entire amateur community may benefit.

F-layer skip

Perhaps the least frequently occuring DX mode for the vhf operator is F-layer skip. It can produce exciting contacts out to 8000 km (5000 miles) or so on the 50-MHz band. During sun-spot-cycle peaks, the F-layer maximum usable frequency can exceed 50 MHz, producing world-wide DX contacts similar to those experienced on ten meters. Very intense F-layer signals on 28 MHz will indicate that the MUF may be rising into the vhf spectrum. Monitor the public service band between 30 and 50 MHz to follow the MUF. British amateur signals on 70 MHz were heard on the East Coast of the U.S. during the 1958 sunspot cycle peak, indicating that trans-continental six-meter DX is entirely possible.

High power and elaborate antennas are usually not required when the band is open via the F-layer. Moderately equipped six-meter stations have successfully worked this mode with S9 signals. Short calls and listening periods are more likely to produce results, as the MUF may rise past 50 MHz for a very short time. The standard calling frequency of 50.110 is probably the best spot to watch.

The vhf bands offer exciting DX possibilities when the basic mechanisms of propagation are understood. Constant monitoring of weather conditions, public service communications, TV broadcasts, and the ten-meter band provide the vhf operator with the indicators he may need to take full advantage of the DX modes. In addition, the more esoteric modes, such as TE scatter, are relatively uncharted, so an amateur station may substantially contribute to the body of knowledge relating to vhf. I hope these tips will encourage more of you to enter the fascinating and challenging world of vhf-DX.

HRH

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